

High-frequency signal switching

The invention relates to a high-frequency signal processing apparatus, such as a reception apparatus, and circuits used in connection with such an apparatus.

Typical examples of high-frequency reception apparatuses are video recorders and mobile telephones. Such apparatuses have RF switches that must operate reliably, using a simple design and a small amount of power. A video recorder, for example, must be able to provide a passive RF coupling from its antenna input to its TV set output when the video recorder is switched off, and to switch off said coupling when the video recorder is switched on.

PCT patent application WO99/55085, for example, discloses a video recorder with an RF switch that is provided with a first capacitor, a main current channel of a field effect transistor and a second capacitor coupled successively between the input and output. The gate of the field effect transistor is grounded. To control the switch, a resistor is provided between a control input and an internal node between the first capacitor and the main current channel of the transistor. By varying the voltage at the control input, the main current channel of the transistor can be made conductive or non-conductive, dependent on whether the RF switch should be turned on or off. Preferably, a normally-on transistor is used (which is conductive when no voltage difference is present between gate and source). Thus, a switch is realized that requires no power supply to pass the RF signal, using a very simple circuit.

Unfortunately, it has been found that such a switch does not provide enough isolation when the switch is off. A T-type circuit which improves the isolation is known from Japanese Patent Abstract publication No. 63-93217. Instead of a single main current channel between the switch input and the switch output, a series connection of the main current channels of a first and a second transistor is used, forming the horizontal branches of the "T". An internal node between the two main current channels is coupled to ground via the main current channel of a third transistor to form the leg of the "T". When the switch is on, the main current channels of the first and the second transistor are made conductive and the main current channel of the third transistor is made non-conductive. When the switch is off, the

main current channels of the first and the second transistor are made non-conductive and the main current channel of the third transistor is made conductive. Thus, a better isolation is realized when the switch is off.

However, this is at the expense of a more complicated control circuit, because
5 the third transistor has to be operated in phase opposition to the first and the second transistor. This does not even allow the switch to switch off completely when the supply voltage is off.

10 It is, inter alia, an object of the invention to provide an apparatus having a signal switch which can be controlled with a less complicated circuit that passes signals when no power is supplied to the switch.

It is a further object of the invention to provide an apparatus having a signal switch that needs a minimal number of components to control the switch and yet provides a
15 good on/off transmission ratio.

The invention provides an apparatus as set forth in claim 1. By using a T-type attenuator structure with a diode in the leg of the T and "normally-on" transistors in the branches of the T, a switch is realized that is "on" when no power supply voltage is applied. Moreover, this circuit makes it possible to use the internal node to apply the control voltage
20 that switches the switch off to both the transistors and the diode. Separate connections are not needed and no capacitors are needed to isolate the control voltage of the transistors and the diode from one another.

In a further embodiment, the control voltage is applied to the internal node via the diode. Thus it is possible to generate a large voltage difference between the control
25 electrode and the channel of the transistors, ensuring a high ratio between the impedance of the transistors in the on and off-states. As a result, the circuit is robust against spread in threshold values of the transistors and subthreshold leakage.

30 These and other objects and advantageous aspects of the apparatus and the switch according to the invention will be described in more detail, using the following Figure.

Fig. 1 shows an apparatus with a signal switch.

Fig. 1 shows an apparatus with a signal switch 10, a control circuit 12, an antenna input 14 and a processing system 16. The signal switch 10 is connected between the antenna input 14 and an output 18b of the apparatus. The processing system 16 is connected to the antenna input 14 and the output 18b. Then control circuit 12 is coupled to the signal switch 10 and is controlled from the processing system 16.

The signal switch 10 contains a first field effect transistor 100, a second field effect transistor 102, a diode 104, a decoupling capacitor 105, a resistor 106 and a pair of capacitors 108a,b. The first and second transistors are of the "normally-on" type (depletion transistors), that is, they have a negative threshold voltage so that the main current channel conducts when the potential difference between the control electrode and the main current channel is zero. The main current channel becomes isolating (substantially without induced mobile charge carriers) only when the potential of the control electrode is at a potential more than a threshold below the potential of the main current channel. For example, transistors with a threshold of -3.5 Volts may be used (that is, a relatively large threshold voltage, so that the transistor is solidly on, with a low channel resistance, when the gate-source voltage is zero. Such a high threshold voltage is possible because the diode 104 is not connected in parallel with the gate-source of the transistors, as far as DC voltages are concerned). The diode 104 is preferably a silicon "PIN" diode, which has a low junction capacitance when it is reverse-biased. (PIN refers to the doping profile, which has a substantially undoped intrinsic region between the anode and the cathode of the diode.)

A signal input 18a of the switch 10 is coupled to a signal output 18b (which forms the output 18b) via, successively, a first one 108a of the capacitors, the main current channel of the first field effect transistor 100, an internal node 101, the main current channel of the second transistor 102 and a second one of the capacitors 108b. The control electrodes of the first and the second field effect transistor 100, 102 are coupled to a common conductor 107. The resistor 106 is coupled between the internal node 101 and this common conductor 107. An output of the control circuit 12 is coupled to the common conductor 107 and to the internal node 101, the latter via diode 104 in the forward direction. This output of the control circuit 12 is coupled to the common conductor 107 via decoupling capacitor 105.

In operation, an RF signal is received by antenna input 14. When processing system 16 is active, it processes the signal and produces an output signal that is applied to output 18b. In this case, processing system 16 controls control circuit 12 to make signal switch 10 block this signal. Control circuit 12 realizes this by applying a positive voltage of,

for example, 5 Volts to the anode of diode 104, relative to common conductor 107, forward-biasing the diode 104. This results in application of a positive voltage to internal node 101 relative to the common conductor 107. This positive voltage is equal to the voltage at the anode of the diode minus a voltage drop across the diode 104, which is approximately 0.7
5 Volts in the case of a silicon diode, so that the voltage difference between the internal node and the common conductor 107 is, for example, 4.3 Volts. Thus, the voltage of the control electrodes of the first and second transistors 100, 102 is substantially below that of the main current channels of the first and second transistors 100, 102, causing conduction through the main current channels of these transistors to be cut off. At the same time, the diode 104 is
10 forward-biased, causing it to have a low dynamic resistance, which is coupled to the common conductor via decoupling capacitor 105. As a result, an "off" state of the signal switch 10 is realized in which the main current channels of transistors 100, 102 and diode 104 form a T-type attenuator between input 18a and output 18b with a large attenuation factor.

When processing system 16 is not active, control circuit 12 commands signal
15 switch 10 to pass the RF signal from its input 18a to its output 18b. This is realized with a zero-voltage difference between the anode of diode 104 and the common conductor 107. As a result, there is no voltage difference between the anode and cathode of the diode 104, nor between the control electrode and the main current channel of the transistors 100, 102. Diode 104 is not forward-biased and therefore has a high dynamic resistance. At the same time, the
20 main current channels of the transistors 100, 102 are conductive. Thus, an "on" state of the signal switch 10 is realized with a signal passage with low attenuation between the input 18a and the output 18b. It will be noted that this "on" state of the signal switch 10 does not require any voltage difference to be applied to the signal switch 10. The on-state can be realized without a need for a voltage difference from a supply voltage source. Of course, the
25 on-state may also be realized when a supply voltage difference is present, by applying a zero-voltage difference between the anode of diode 104 and common conductor 107 (or more generally a voltage difference that is smaller than the voltage needed for forward-biasing diode 104), on a command from processing system 16, when it is needed to pass the signal from the input 18a to the output 18b.

30 Resistor 106 is primarily used to determine the current through diode 104 when this diode 104 is forward-biased. This current is preferably made sufficiently high to ensure a sufficiently low dynamic resistance of diode 104 in the off-state of switch 10. When only very small currents are needed, parasitic resistances may be used instead of resistance 106. In order to realize a minimum of attenuation in the on-state, a diode 104 with a small

diode capacitance is preferably used, such as a PIN diode. Capacitors 108a,b serve to isolate the internal node 101 from the input and output 18a,b. Thus, control of the switch 10 is made independent of any DC voltages at the input 18a and output 18b. Of course capacitors 108a,b may be omitted when no DC voltage is applied to the input and output 18a,b, or when the applied DC voltage does not affect operation of the switch 10. Decoupling capacitor 105 need not be present explicitly, its function may be provided, for example, by the power supply of the circuit. However, for high-frequency signals, an explicit decoupling capacitor 105 is preferably used. As shown in Fig. 1, a common conductor 107 is used both for applying voltages to the control electrodes of transistors 100, 102 and as a common terminal for signal input and output, but of course these need not be directly connected. Instead, decoupling capacitor 105 may be coupled to the common terminal for signal input and output, and the control electrodes of the transistors and resistor 106 may be coupled to an internal common conductor 107.

Although the control electrodes of the transistors 100, 102 are shown connected directly to the common conductor 107, components may be added in this connection without affecting the principle of operation of the circuit, because no DC current flows through the connections. Similarly, a component such as a second diode or a small resistance may be added in series with diode 104 without affecting the principle of operation of the circuit, although this may decrease isolation in the "off" state. Likewise, components such as small resistors may be included in series with the main current channels of the transistors 100, 102 without affecting the principle of operation, although this will increase attenuation in the "on" state.

As an alternative, diode 104 and resistance 106 could be exchanged, so that diode 104 is arranged between internal node 101 and common conductor 107 with its anode connected to the internal node 101, and resistance 106 is coupled between the output of control circuit 12 that is not connected to the common conductor 107 and the internal node 101. In this arrangement, the voltage difference between the control electrodes of transistors 100, 102 and their main current channels is equal to the forward bias voltage of diode 104 in the off-state of the switch. This means that the threshold voltage of the transistors 100, 102 must be in the narrow range between zero and this forward bias voltage. A low threshold voltage is needed in this alternative, resulting in a higher resistance and higher losses. Also, the value of the threshold voltage is much more critical in this alternative.